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Thermal Neutron Detection Using Alkali Halide Scintillators with ^{6}Li and Pulse Shape Discrimination

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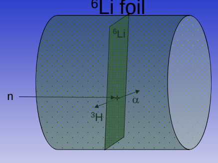
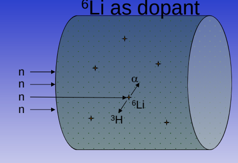
Introduction



An ideal ^{3}He detector replacement for the short- to medium-term future will use materials that are easy to produce and well understood, while maintaining thermal neutron detection efficiency and gamma rejection close to the ^{3}He performance. We are investigating the use of standard alkali halide scintillators interfaced with ^{6}Li and read out with PMTs. Thermal neutrons are captured on ^{6}Li with high efficiency, emitting high-energy α and triton reaction products. These particles deposit energy in the scintillator, providing a thermal neutron signal; discrimination against gamma interactions is possible via pulse shape discrimination (PSD), since heavy particles produce faster pulses in inorganic scintillating crystals.

In one class of detectors (examples pictured at left), a thin (~50 μm) Li foil is used as a conversion layer with NaI and CsI crystals. NaI(Tl) is a more common and faster scintillator, but CsI(Tl) and CsI(Na) are easier to handle and have excellent PSD characteristics.

In the second class of detectors (examples pictured at right), lithium is used as a dopant in NaI. We successfully formed a solid solution with ~5% molar concentration of lithium, and produced polycrystalline NaI(Tl,Li) samples via a hot forging process. Transparency of the samples was inconsistent, and this class of materials needs further dedicated study.



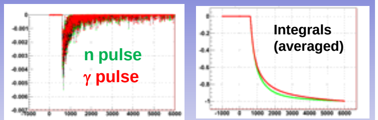
Measurement Methods

For these feasibility studies, natural lithium salts and foils were used, with about 7% ^{6}Li abundance. Each detector assembly was wrapped in a diffuse reflector and coupled with optical grease to a PMT. Pulse shapes were acquired with a 500 MHz digitizer and written to disk for offline analysis.

Each pulse is analyzed for amplitude, the integral of the acquired pulse over baseline, and a PSD parameter, the number of samples required to integrate from (typically) 10% to 80% of the area under the pulse. This is roughly a digital equivalent of the zero-crossing method.

To measure the thermal neutron detection efficiency, we use a ^{252}Cf source and place both source and detector in a cave constructed of HDPE and paraffin. A ^{3}He detector with known sensitivity is used to calibrate the efficiency measurements.

Detector/PMT assembly with Cf-252 source.

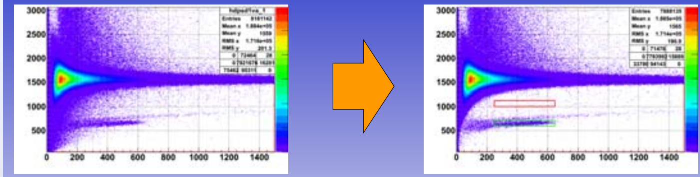


Left: Examples of acquired γ and n pulses. **Right**: Averaged integral pulses, showing the n/γ separation.

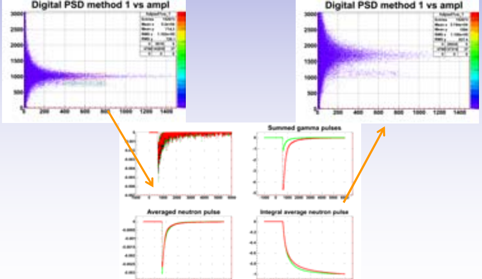
HDPE/paraffin cave used for neutron thermalization.

Pulse Processing

Since the discrimination between thermal neutron capture events and gamma backgrounds relies on pulse shape analysis, the results can be sensitive to the details of pulse processing.



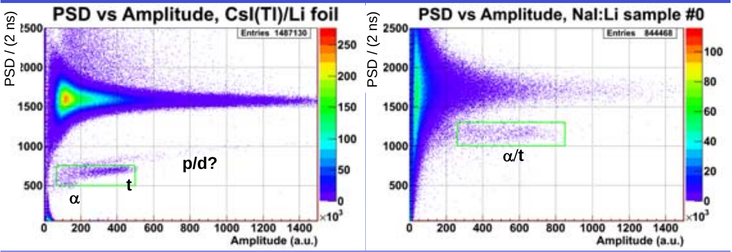
All of the digital processing starts with a determination of the baseline, which can vary slightly from pulse to pulse. The baseline is estimated from pre-trigger samples, but the estimate is sometimes compromised by signal or noise in the pre-trigger. We developed a procedure to reject events with too much pre-trigger variation, and significantly cleaned up the PSD vs amplitude plot in the important region between gamma and neutron PSD values.



For the samples based on NaI(Tl), we found the 10%-80% PSD method was not optimal. By bootstrapping on the non-optimal PSD and averaging the well-identified pulses, we extracted more optimal algorithm parameters for NaI(Tl): 10%-50%.

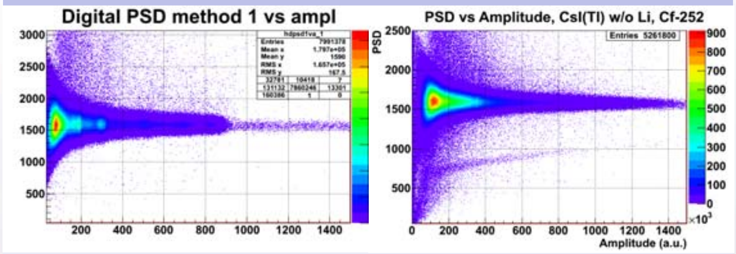
Results

Shown here are plots of PSD vs Amplitude in the presence of Cf-252 and moderator for a CsI(Tl)/Li foil detector, and a NaI(Tl,Li) detector. In both cases, a clear thermal neutron capture signal is seen at low PSD values relative to the gamma-dominated background. Green boxes identify the signal region used in offline analysis. From these and other runs, we estimate the thermal neutron detection efficiency, and the gamma rejection rate.



Sample	Active area	Thermal n efficiency		γ rejection
		Measured (nat. Li)	Extrapolate 100% Li-6	
NaI(Tl) + Li foil	5 cm^2	0.7%	8.4%	??
CsI(Tl) + Li foil	5 cm^2	0.8%	10%	2E-6 – 1E-7
NaI(Tl):LiI	1.3 cm^2	3.4%	37%	Insufficient
		± 20% (rel)	± 30% (rel)	

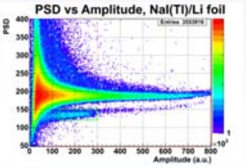
Calibration runs



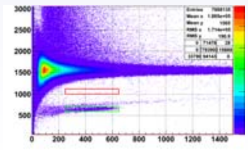
Gamma-only run (Th-232) used for gamma rejection measurement.

No-foil run for fast neutron sensitivity measurement. This plot does not include baseline cleanup.

Additional samples



NaI(Tl)/Li foil detector results. We observe the thermal neutron capture signal, but with less PSD separation.



CsI(Na)/Li foil detector results. Very similar to CsI(Tl)/Li foil.

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